

# Diphoton Revelation of the Utilitarian Supersymmetric Standard Model

Ernest Ma

*Physics & Astronomy Department and Graduate Division,  
University of California, Riverside, California 92521, USA*

*HKUST Jockey Club Institute for Advanced Study,  
Hong Kong University of Science and Technology, Hong Kong, China*

## Abstract

In 2002, I proposed a unique  $U(1)$  extension of the supersymmetric standard model which has no  $\mu$  term and conserves baryon number and lepton number separately and automatically. This model, without any change, has all the necessary and sufficient ingredients to explain the possible 750 GeV diphoton excess, observed recently by the ATLAS Collaboration at the Large Hadron Collider (LHC). It is associated with the superfield which replaces the  $\mu$  parameter. If confirmed and supported by subsequent data, it may even be considered as the first evidence for supersymmetry.

Since the recent announcement [1] by the ATLAS Collaboration at the Large Hadron Collider (LHC) of a diphoton excess around 750 GeV, numerous papers [2] have appeared explaining its presence or discussing its implications. In this short note, I simply point out that an explicit model I proposed in 2002 [3] has exactly all the necessary and sufficient particles and interactions for this purpose. They were of course there for solving other issues in particle physics. However, the observed diphoton excess may well be a first revelation of this model, including its connection to dark matter.

This 2002 model extends the supersymmetric standard model by a new  $U(1)_X$  gauge symmetry. It replaces the  $\mu$  term with a singlet scalar superfield which also couples to heavy color-triplet superfields which are electroweak singlets. The latter are not *ad hoc* inventions, but are necessary for the cancellation of axial-vector anomalies. It was shown in Ref. [3] how this was accomplished by the remarkable exact factorization of the sum of eleven cubic terms, resulting in two generic classes of solutions. Both are able to enforce the conservation of baryon number and lepton number up to dimension-five terms. As such, both the scalar singlet and the vectorlike quarks are essential predictions of this 2002 model. They are thus naturally suited for explaining the observed diphoton excess. In 2010 [4], I discussed a specific version which will be used here as well to illustrate my point.

Model : Consider the gauge group  $SU(3)_C \times SU(2)_L \times U(1)_Y \times U(1)_X$  with the particle content of Ref. [3]. For  $n_1 = 0$  in Solution (A), the various superfields transform as shown in Table 1. There are three copies of  $Q, u^c, d^c, L, e^c, N^c, S_1, S_2$ ; two copies of  $U, U^c, S_3$ ; and one copy of  $\phi_1, \phi_2, D, D^c$ . The only allowed terms of the superpotential are thus trilinear, i.e.

$$Qu^c\phi_2, \quad Qd^c\phi_1, \quad Le^c\phi_1, \quad LN^c\phi_2, \quad S_3\phi_1\phi_2, \quad N^cN^cS_1, \quad (1)$$

$$S_3UU^c, \quad S_3DD^c, \quad u^cN^cU, \quad u^ce^cD, \quad d^cN^cD, \quad QLD^c, \quad S_1S_2S_3. \quad (2)$$

The absence of any bilinear term means that all masses come from soft supersymmetry breaking, thus explaining why the  $U(1)_X$  and electroweak symmetry breaking scales are

Table 1: Particle content of proposed model.

Superfield	$SU(3)_C$	$SU(2)_L$	$U(1)_Y$	$U(1)_X$
$Q = (u, d)$	3	2	1/6	0
$u^c$	$3^*$	1	-2/3	3/2
$d^c$	$3^*$	1	1/3	3/2
$L = (\nu, e)$	1	2	-1/2	1
$e^c$	1	1	1	1/2
$N^c$	1	1	0	1/2
$\phi_1$	1	2	-1/2	-3/2
$\phi_2$	1	2	1/2	-3/2
$S_1$	1	1	0	-1
$S_2$	1	1	0	-2
$S_3$	1	1	0	3
$U$	3	1	2/3	-2
$D$	3	1	-1/3	-2
$U^c$	$3^*$	1	-2/3	-1
$D^c$	$3^*$	1	1/3	-1

not far from that of supersymmetry breaking. As  $S_{1,2,3}$  acquire nonzero vacuum expectation values (VEVs), the exotic  $(U, U^c)$  and  $(D, D^c)$  fermions obtain Dirac masses from  $\langle S_3 \rangle$ , which also generates the  $\mu$  term. The singlet  $N^c$  fermion gets a large Majorana mass from  $\langle S_1 \rangle$ , so that the neutrino  $\nu$  gets a small seesaw mass in the usual way. The singlet  $S_{1,2,3}$  fermions themselves get Majorana masses from their scalar counterparts  $\langle S_{1,2,3} \rangle$  through the  $S_1 S_2 S_3$  terms. The only massless fields left are the usual quarks and leptons. They then become massive as  $\phi_{1,2}^0$  acquire VEVs, as in the minimal supersymmetric standard model (MSSM).

Because of  $U(1)_X$ , the structure of the superpotential conserves both  $B$  and  $(-1)^L$ , with  $B = 1/3$  for  $Q, U, D$ , and  $B = -1/3$  for  $u^c, d^c, U^c, D^c$ ;  $(-1)^L$  odd for  $L, e^c, N^c, U, U^c, D, D^c$ , and even for all others. Hence the exotic  $U, U^c, D, D^c$  scalars are leptoquarks and decay into ordinary quarks and leptons. The  $R$  parity of the MSSM is defined here in the same way,

i.e.  $R \equiv (-)^{2j+3B+L}$ , and is conserved. Note also that the quadrilinear terms  $QQQL$  and  $u^c u^c d^c e^c$  (allowed in the MSSM) as well as  $u^c d^c d^c N^c$  are forbidden by  $U(1)_X$ . Proton decay is thus strongly suppressed. It may proceed through the quintilinear term  $QQQLS_1$  as the  $S_1$  fields acquire VEVs, but this is a dimension-six term in the effective Lagrangian, which is suppressed by two powers of a very large mass, say the Planck mass, and may safely be allowed.

Gauge sector : The new  $Z_X$  gauge boson of this model becomes massive through  $\langle S_{1,2,3} \rangle = u_{1,2,3}$ , whereas  $\langle \phi_{1,2}^0 \rangle = v_{1,2}$  contribute to both  $Z$  and  $Z_X$ . The resulting  $2 \times 2$  mass-squared matrix is given by [5]

$$\mathcal{M}_{Z,Z_X}^2 = \begin{pmatrix} (1/2)g_Z^2(v_1^2 + v_2^2) & (3/2)g_Z g_X(v_2^2 - v_1^2) \\ (3/2)g_Z g_X(v_2^2 - v_1^2) & 2g_X^2[u_1^2 + 4u_2^2 + 9u_3^2 + (9/4)(v_1^2 + v_2^2)] \end{pmatrix}. \quad (3)$$

Since precision electroweak measurements require  $Z-Z_X$  mixing to be very small [6],  $v_1 = v_2$ , i.e.  $\tan \beta = 1$ , is preferred. With the 2012 discovery [7, 8] of the 125 GeV particle, and identified as the one Higgs boson  $h$  responsible for electroweak symmetry breaking,  $\tan \beta = 1$  is not compatible with the MSSM, but is perfectly consistent here, as shown already in Ref. [4].

Consider the decay of  $Z_X$  to the usual quarks and leptons. Each fermionic partial width is given by

$$\Gamma(Z_X \rightarrow \bar{f}f) = \frac{g_X^2 M_{Z_X}}{24\pi} [c_L^2 + c_R^2], \quad (4)$$

where  $c_{L,R}$  can be read off under  $U(1)_X$  from Table 1. Thus

$$\frac{\Gamma(Z_X \rightarrow \bar{t}t)}{\Gamma(Z_X \rightarrow \mu^+\mu^-)} = \frac{\Gamma(Z_X \rightarrow \bar{b}b)}{\Gamma(Z_X \rightarrow \mu^+\mu^-)} = \frac{27}{5}. \quad (5)$$

This will serve to distinguish it from other  $Z'$  models [9].

Relevance to the observed diphoton excess : In this model, other than the addition of  $N^c$  for seesaw neutrino masses, the only new particles are  $U, U^c, D, D^c$  and  $S_{1,2,3}$ , which are exactly

the ingredients needed to explain the diphoton excess at the LHC. The allowed  $S_3UU^c$  and  $S_3DD^c$  couplings enable the one-loop gluon production of  $S_3$  in analogy to that of  $h$ . The one-

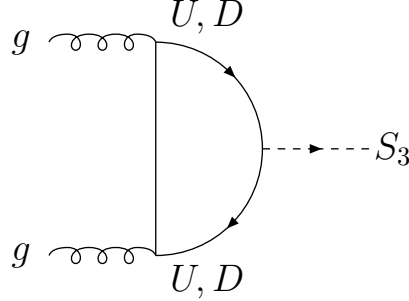


Figure 1: One-loop production of  $S_3$  by gluon fusion.

loop decay of  $S_3$  to two photons comes from these couplings as well as  $S_3\phi_1\phi_2$ . In addition,

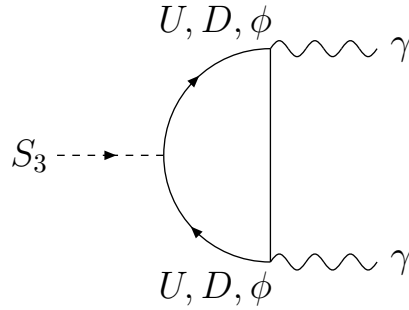


Figure 2: One-loop decay of  $S_3$  to two photons.

the direct  $S_1S_2S_3$  couplings enable the decay of  $S_3$  to other final states, including those of the dark sector, which contribute to its total width. The fact that the exotic  $U, U^c, D, D^c$  scalars are leptoquarks is also very useful for understanding [10] other possible LHC flavor anomalies. In a nutshell, a desirable comprehensive picture of possible new physics beyond the standard model is encapsulated by this existing model. Note that there are two copies of  $S_3$ , so it is possible that the 750 GeV particle is a pseudoscalar. This has the advantage that it does not mix with the 125 GeV Higgs scalar.

The phenomenological analysis to support the above claim is similar to all other recent proposals using this mechanism, and follows closely that of Ref. [10], including the necessary

addition of the contribution of the color-singlet charged  $\phi$  fermions to increase the  $S_3 \rightarrow \gamma\gamma$  rate. Note that this is predicted by the model and not an *ad hoc* invention. The possibility of  $S_3 \rightarrow S_1 S_2$  here could also enhance its invisible width and serves as a link to dark matter.

Predictions: Since  $S_3$  couples to leptoquarks, the  $S_3 \rightarrow l_i^+ l_j^-$  decay must occur at some level. As such,  $S_3 \rightarrow e^+ \mu^-$  would be a very distinct signature at the LHC. Its branching fraction depends on unknown Yukawa couplings which need not be very small. Similarly, the  $S_3$  couplings to  $\phi_1 \phi_2$  as well as leptoquarks imply decays to  $ZZ$  and  $Z\gamma$  with rates comparable to  $\gamma\gamma$ .

Conclusion: The utilitarian supersymmetric  $U(1)_X$  gauge extension of the Standard Model of particle interactions proposed 14 years ago [3] allows for two classes of anomaly-free models which have no  $\mu$  term and conserve baryon number and lepton number automatically. A simple version [4] with leptoquark superfields is especially interesting because of existing LHC flavor anomalies.

The new  $Z_X$  gauge boson of this model has specified couplings to quarks and leptons which are distinct from other gauge extensions and may be tested at the LHC. On the other hand, a hint may already be discovered with the recent announcement by ATLAS of a diphoton excess at around 750 GeV. It may well be the revelation of the singlet scalar (or pseudoscalar)  $S_3$  predicted by this model which also predicts that there should be singlet leptoquarks and other particles that  $S_3$  must couple to. Consequently, gluon fusion will produce  $S_3$  which will then decay to two photons together with other particles, including those of the dark sector. This scenario explains the observed diphoton excess, all within the context of the original model, and not an invention after the fact.

Most importantly, since  $S_3$  replaces the  $\mu$  parameter, its identification with the 750 GeV excess implies the existence of supersymmetry. If confirmed and supported by subsequent data, it may even be considered in retrospect as the first evidence for the long-sought exis-

tence of supersymmetry.

Acknowledgement : This work was supported in part by the U. S. Department of Energy Grant No. de-sc0008541.

## References

- [1] M. Kado (for the ATLAS Collaboration), seminar at CERN, December 15, 2015.
- [2] There are over 150 papers on the arXiv since December 15, 2015.
- [3] E. Ma, Phys. Rev. Lett. **89**, 041801 (2002).
- [4] E. Ma, Phys. Rev. **D81**, 097701 (2010).
- [5] E. Keith and E. Ma, Phys. Rev. **D56**, 7155 (1997).
- [6] J. Erler, P. Langacker, S. Munir, and E. R. Pena, JHEP **0908**, 017 (2009).
- [7] G. Aad *et al.* (ATLAS Collaboration), Phys. Lett. **B716**, 1 (2012).
- [8] S. Chatrchyan *et al.* (CMS Collaboration), Phys. Lett. **B716**, 30 (2012).
- [9] S. Godfrey and T. A. W. Martin, Phys. Rev. Lett. **101**, 151803 (2008).
- [10] M. Bauer and M. Neubert, arXiv:1512.06828 [hep-ph].